National Bureau of Standards

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New Data on Automotive Combustion

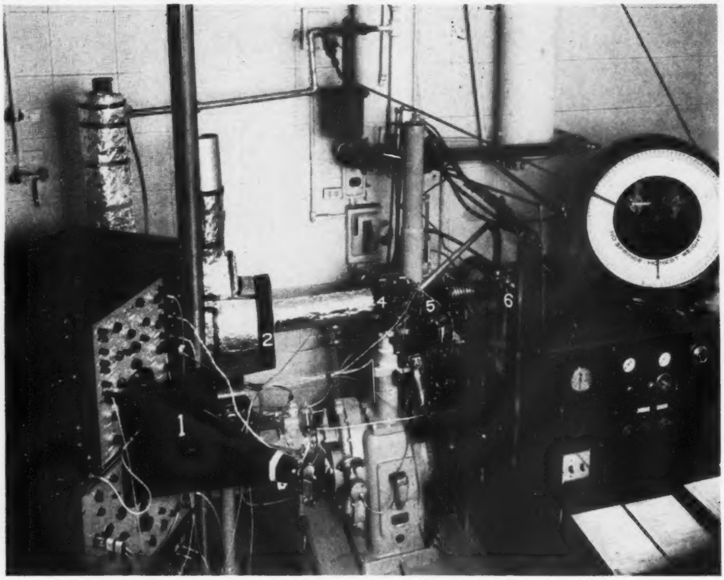
research on the nature of engine knock

RESEARCH on engine combustion at the National Bureau of Standards is providing much valuable information on the chemical processes that take place within the cylinders of an automotive engine during the combustion cycle. By use of a very fast acting valve previously developed by NBS it has been possible to take samples of the rapidly changing combustion gas over extremely short intervals. Analysis of these samples has yielded detailed knowledge of the proportions of reactants and products present at various stages of the cycle. The data thus obtained provide a basis for increased understanding of the mechanism of engine knock and carbon formation in the cylinders.

As the compression ratios of modern gasoline engines are continually raised, increasing difficulty is being caused by knock and preignition. The rapidly expanding use of Diesel engines has also emphasized problems of cold starting and engine roughness and smoking under heavy-load operation. All these difficulties are associated with the combustion phenomenon known as *autoignition*, which occurs when a fuel-air mixture is heated by compression until it ignites spontaneously without spark. Fuel injected into the hot air in a Diesel cylinder ignites by this process, while knock in a gasoline engine is caused by explosive autoignition of the last, unburned portion of the fuel-air mixture to be traversed by the normal flame from the spark plug.

Seeking information that will lead to more efficient utilization of fuels, W. J. Levedahl and C. R. Yokley of the NBS engine fuels laboratory have been conducting an intensive investigation of autoignition. Their apparatus includes a special single-cylinder engine of variable compression ratio in which a wide range of operating conditions may be simulated. The engine has been modified to permit the compression-ignition of a single homogeneous premixed charge of fuel and air in the absence of burned residual gases, cylinder hot spots, and lubricating oil. Pressure, rate of change of pressure, and light emission are oscillographically recorded as functions of crank angle or time. At any preselected time during the course of the reaction the special sampling valve can be used to remove a sample from the reacting mixture during an interval of about 0.2 to 0.3 millisecond. Use of this valve enables the reaction to be followed by mass spectrometric means, as suggested by Dr. E. U. Condon.

Experiments have been carried out in the single-cylinder engine on a number of hydrocarbon fuels of various chemical structures. In general, it has been found that the autoignition of a paraffinic hydrocarbon occurs in a series of steps. The first detectable reaction is the formation of peroxides at a temperature between 600° and 800° F. At a somewhat higher temperature, after peroxide concentration has become appreciable, a blue luminescence called the *cool flame* appears, accompanied by a substantial increase in temperature and pressure. When the temperature has risen to about 1,100° F, the rate of reaction suddenly increases at a rapid rate as the *hot flame* begins. The accompanying violent pressure rise initiates a pressure wave

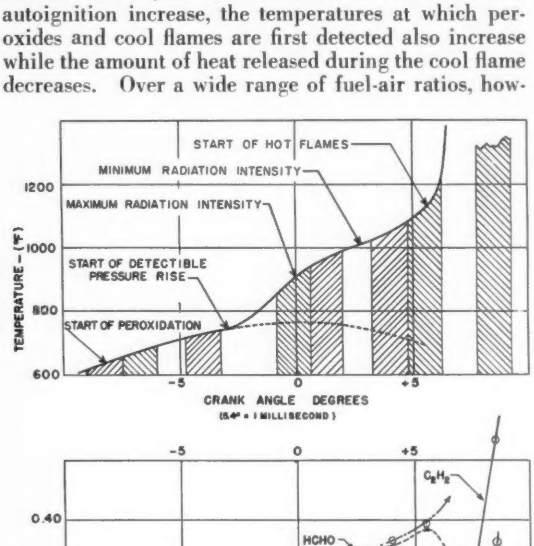


Apparatus used at NBS in studies of the mechanism of combustion in gasoline engines. A special single-cylinder engine permits a single homogeneous fuel-air charge to be ignited by compression in the absence of residual exhaust gases, cylinder hot spots, and lubricating oil. Fuel metered by the flow system (6) is mixed with air in the vaporizing tank (2). Compression ignition occurs in the cylinder (4), which is isolated from crankcase oil by a crosshead (3). Pressure and radiation-intensity data are photographically recorded from two dual-beam oscilloscopes (1). Gas samples are taken over an interval of about 0.2 to 0.3 millisecond with a fast-acting sampling valve (5).

that is reflected back and forth across the combustion space, causing audible knock.

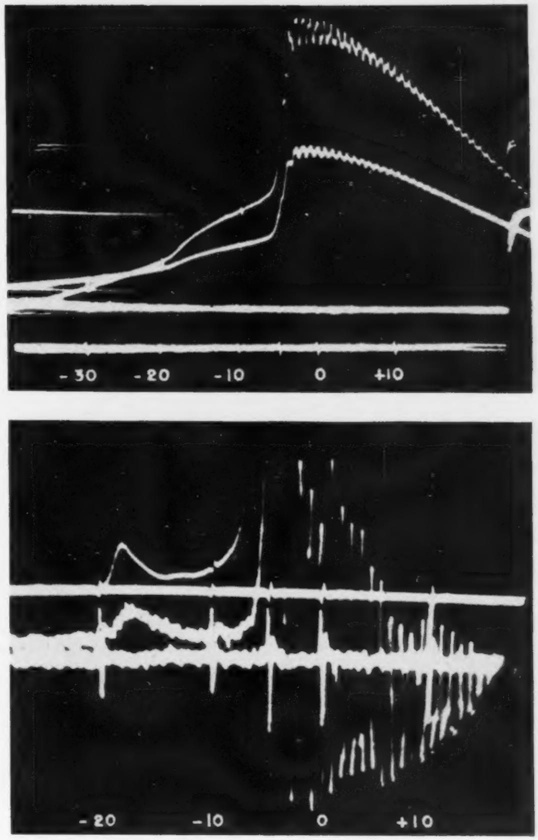
Investigation of many pure hydrocarbons, isooctane-*n*-heptane blends, and oxygen-containing compounds has shown that, as octane number and resistance to autoignition increase, the temperatures at which peroxides and cool flames are first detected also increase while the amount of heat released during the cool flame decreases. Over a wide range of fuel-air ratios, however, the temperatures at which hot flames first appear lie in the same temperature range—1,100° F ± 50°—for all aliphatic compounds studied. Because the octane numbers and autoignition resistances of the fuels investigated vary widely, these properties are thought to be functions of the extent of "self-heating" in the early stages of the reaction. According to this view of the over-all process, a very high-octane fuel must be heated by compression alone to nearly 1,100° F before hot flames begin, whereas a low-octane fuel may contribute several hundred degrees of the required temperature rise by its own early reactions. Thus, the ease with which low-octane fuel autoignites is probably due to the large contribution of the cool-flame reactions in raising the mixture temperature to the necessary 1,100° F. The fact that the hot-flame stage of combustion begins at very nearly the same temperature for all fuels may indicate that this stage takes place as the result of the production of a single essential intermediate compound during the earlier stages of reaction. Or perhaps the reactions that occur are common to all the fuels studied.

While *n*-hexane was being used as a fuel in the variable-compression engine, eight samples of the combustion gas were removed and analyzed in the mass spectrometer. Mixture composition was then plotted as a function of time during autoignition. When a lean mixture was used, no large change in chemical



Composition-time and temperature-time diagrams plotted from data on *n*-hexane autoignition. In lower diagram the concentration of each component as determined in the mass spectrometer is shown in terms of its partial pressure referred to partial pressure of nitrogen in mixture. Shaded areas in upper curve represent timing and duration of gas samples. Dotted line in upper curve represents the temperature time relationship for nonreactive mixture in which autoignition would not take place.

Typical oscillograms obtained by the Bureau in studies of autoignition in a lean *n*-heptane mixture. The two traces in the upper photograph are pressure-vs-crank angle (or pressure-vs-time) curves, with different amplification, for a single compression-ignition cycle. In the lower photograph the bottom curve shows rate of pressure rise while the other curve shows radiation intensity. The cool flame begins at about 19° before top center; the hot flame starts at about 6° before top center and is followed by violent knock vibrations. (5.4° of crank angle is equivalent to 1 millisecond.)



composition occurred between the start of peroxidation and the beginning of intense cool flames. During the cool flame, however, the hexane decomposed into several olefins, acetylene formaldehyde, carbon monoxide, carbon dioxide, and water. By the time the hot flame began only about one-third of the hexane had decomposed, and this small amount of fuel had undergone sufficient oxidative degradation to cause a temperature rise of about 450° F. In the early part of the hot flame most of the original fuel and fragments, including formaldehyde, were decomposed, while hydrogen and acetylene were formed in larged quantities along with small amounts of diolefins and benzene.

Other sample analyses made with a series of branched and cyclic paraffins show that these fuels all produce olefins, carbon oxides, and water during the early reactions. The lower-octane fuels give larger quantities of these products and, in addition, produce fomaldehyde and acetylene during the cool flame.

The rapid increase of acetylene (C_2H_2) concentration in the hot flame is one of several pieces of information that tend to corroborate the results obtained in the past year by R. E. Ferguson. The results suggest that acetylene is an important intermediate in the hot-flame combustion of hydrocarbons. Work is now being carried on at NBS to determine the part played by acetylene in the earlier stages of combustion.

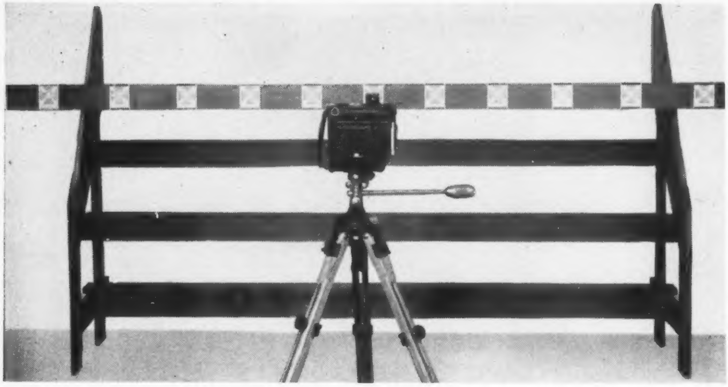
There is also considerable evidence, both from the NBS studies and from those in other laboratories, that acetylene may be the essential intermediate in carbon formation in burning mixtures. Carbon is readily formed in knocking combustion in engines, even with lean mixtures; and this may indicate that the formation of carbon from the acetylene present is a faster reaction than the direct oxidation of acetylene under these conditions.

Test Charts for Amateur Photographers

NEW RESOLUTION test charts devised by Drs. F. E. Washer and I. C. Gardner of the Bureau's optics laboratories provide the amateur photographer with an objective means for testing and rating the lenses of his cameras. The charts are available in 2 values of contrast, each containing 12 different test patterns covering a wide range of line widths. By photographing the line patterns of the charts and counting lines in the resulting negative, the photographer can obtain a numerical measure of the sharpness of the image formed by a given lens and the extent to which the image can be enlarged. It is thus possible to characterize completely the performance of a general-purpose photographic lens. The charts will also be useful in the testing of a variety of optical equipment, such as telescopes, binoculars, and goggle and sunglass lenses.

In recent years the practice of making enlargements of several diameters from the original negative has created a general demand for lenses giving sharper and better defined images than were considered satisfactory a few years ago. A great variety of photographic lenses are now available, and lenses identical in focal length and speed sell at widely different prices. When these lenses are tried out, they are found to differ mainly in the sharpness of the image produced, and this one characteristic is probably the best single basis for determining the quality of a lens.

In evaluating large numbers of airplane camera lenses for other Government agencies, NBS has found that the resolving power of a lens provides an effective means for specifying numerically its ability to form a sharp, well-defined image. A precise instrument for



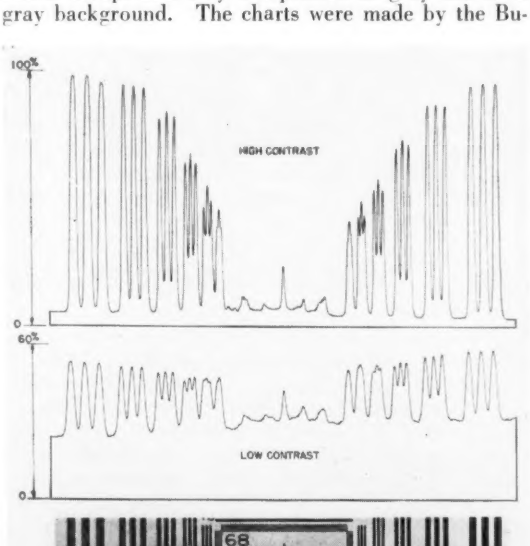
NBS resolution charts arranged before a camera for a test. By photographing the entire series of charts mounted on a board as shown, the photographer can obtain a single negative providing information regarding the resolving power across the entire picture area of the lens. The spacing of the individual charts is such in this arrangement that the angle between successive charts, measured at the camera lens, is 5°.

measuring resolving power has been constructed at NBS, and all airplane camera lenses that are to be used on Government mapping projects are now evaluated on this instrument. Inasmuch as it is not practicable for the Bureau to test hand cameras for the general public, a modified method of making the resolving power test was developed for the convenience of the amateur photographer. With the aid of the charts prepared by NBS, anyone sufficiently skilled in photographic technique to operate a miniature camera can carry out this simplified test with readily improvised apparatus.

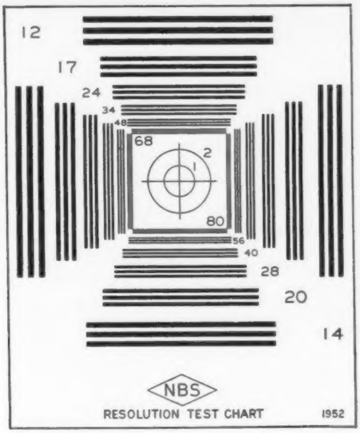
The test is simply a measure of the resolving power of the lens-and-camera combination as shown by the finest pattern of lines on the chart that the combination can render as distinct lines on the negative. When a pattern of parallel lines is photographed, the lines, if sufficiently close together, will appear as a gray patch and will be indistinguishable individually. If, however, the lines in the object are so far apart that the lens records them as distinct lines, the lens is said to "resolve" the lines. Because a given pattern of lines appears finer and is more difficult to resolve as it is placed farther away from the lens, the resolving power is taken as the number of lines per millimeter, measured on the negative rather than on the chart, of the finest pattern resolved. For best results the line patterns on the negative should be examined with a compound microscope of low power (50 diameters is a suitable value) although a good magnifying glass can be used for the coarser patterns. By mounting a series of the charts at equal intervals on a board and photographing the entire setup, a single negative providing information regarding the resolving power across the entire picture area of the lens can be obtained.

Sometimes a lens performs unsatisfactorily because of errors in the focusing scale or in the adjustment of the coupled range finder. Errors of this kind can be detected by photographing the test chart at various distances in front of the lens without changing the position of the lens with respect to the film plane during successive exposures. By suitable selection of distances and proper interpretation of results the direction and approximate magnitude of the focusing error can be determined.

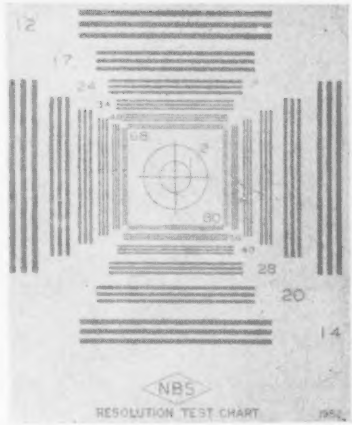
The NBS resolution charts are made up of a number of test patterns arranged symmetrically about a center. Each test pattern consists of a group of three lines, but the width of the lines and the spacing between them varies from group to group, providing a range from 12 to 80 lines per millimeter. The high-contrast charts are printed in black ink on a white background. The low-contrast charts are identical with the high-contrast charts except that they are printed in gray ink on a gray background. The charts were made by the Bu-



Comparative results on axis for a lens tested with high- and low-contrast charts. These curves are microdensitometer traces made by scanning of the negative images of the high- and low-contrast charts. The light area of the reproduction of the chart at the bottom of the figure shows the portion of the image actually scanned.



New resolution test charts devised by the Bureau for use by amateur photographers in testing the quality of their camera lenses. Patterns of the high-contrast chart (left) and the low-contrast chart (right) are identical. When the charts are photographed at the standard distance of 26 focal lengths, the values of resolving power that can be measured range from 12 to 80 lines per millimeter (indicated by numbers along the diagonals), increasing from group to group by a factor equal to the fourth root of 2. The concentric circles at the center of the charts are for use in checking the tolerances of goggle and sunglass lenses.



reau of Engraving and Printing in accordance with detailed specifications regarding width of lines and steps between patterns. Use of a process identical with that employed in the printing of postage stamps insured exact duplication of the test patterns.

In the new NBS charts the lines forming the patterns were made considerably longer than in previous charts of this type. This was done for two reasons. First, the ratio of length to width of the lines was made sufficiently great that the visual resolving power as read would not be subject to variations arising from end effects and the images would continue to look like lines down to the limit of resolution. Second, many laboratories are now equipped with microdensitometers for determining differences in contrast, and the longer lines can be scanned more effectively by such instruments. If shorter lines are preferred, they can be obtained by masking of the lines on the present charts.

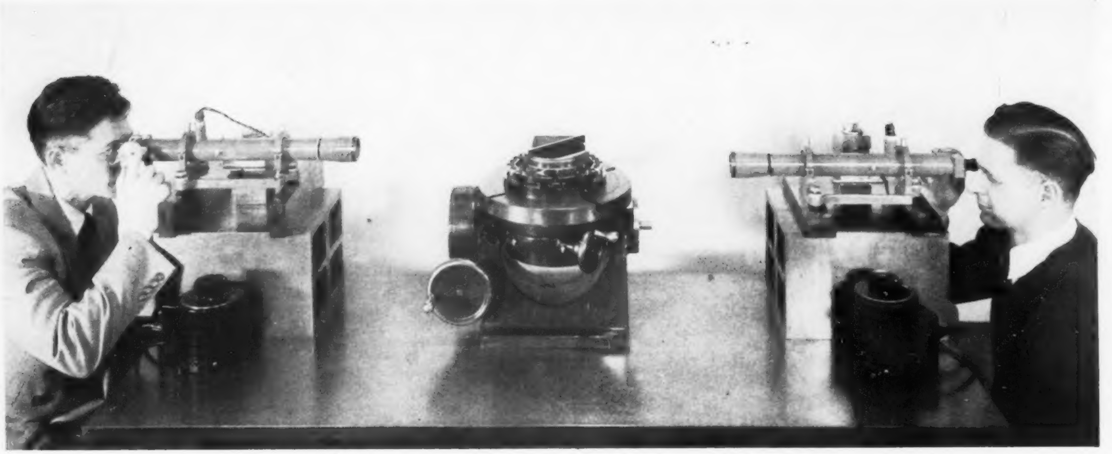
Complete directions by which the amateur photographer can make a resolving-power test of his camera lens with the NBS resolution charts are given in NBS Circular 533, *Method for Determining the Resolving Power of Photographic Lenses*, by Francis E. Washer and Irvine C. Gardner. This circular, which also includes a complete set of the new resolving power charts for both high and low contrast, is available at a cost of $1.00 (34 cents additional for foreign mailing) from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. Additional sets of the new NBS lens resolution charts (1 sheet of 6 high-contrast and 1 sheet of 6 low-contrast charts) have been published as *Supplement to NBS Circular 533* and may be obtained from the Superintendent of Documents for 75 cents a set (25 cents additional for foreign mailing).

NBS Circular 533 is a revision for Circular 428, which appeared in 1940. The new circular takes advantage of some of the advances in the science of optics that have occurred since the first circular was published. Besides providing two values of contrast, the charts included with Circular 533 are more convenient to use and give more precise results than those that were published with Circular 428.

Circular 533 also gives instructions for the testing of goggles, sunglasses, telescopes, and binoculars. Federal Specifications usually require that goggle lenses shall be free from prismatic effect caused by nonparallelism of the lens surfaces, shall have no refractive power, and shall not lower the visual acuity of the wearer. Because it is impracticable to eliminate these defects entirely, tolerances for each have been established. In the case of nonparallelism of surfaces, the prism effect must not exceed $\frac{1}{16}$ prism diopter (4-min angle between surfaces). Provision has been made for this test by placing in the center of the NBS resolution charts a prism target designed to permit the detection of prism effect in excess of $\frac{1}{16}$ diopter. This pattern consists of two concentric circles of such size that their radii subtend angles of 1 and 2 min of arc when viewed at a distance of 35 ft. A simple $\frac{1}{16}$-diopter prism having a refractive index of 1.5 will deviate a beam of light by 2 min of arc. Thus, when observed through a telescope at a distance of 35 ft, the pattern can be used for a go-not-go test for the prismatic effect. The telescope is first alined so that the image of a dot at the center of the circles falls on the cross hairs. Then if the intersection point of the cross hairs falls outside the image of the circle when the goggle lens is held in front of the objective lens of the telescope, the prismatic power of the lens exceeds the tolerance.

The same arrangement can be used to check the refractive power of a goggle lens, which Federal Specifications require shall not exceed +16 diopters. The focusing movement of the telescope is first calibrated for zero power by focusing on the test chart and then for +16-diopter power by interposing a 16-diopter lens in front of the objective lens of the telescope and again focusing on the chart. These two positions of the telescope establish the tolerance limits for the lenses to be tested.

To determine the limits of resolution of telescopes and binoculars the chart is viewed through the instrument at a given distance, and the smallest pattern of lines that is distinctly resolved is noted. The limit of resolution can then be found by reference to a table contained in NBS Circular 533.



Calibration of a 45-deg angle block in the NBS gage laboratory. The new NBS standard polygon and the angle block are mounted on a rotary table (center). The angle block is raised slightly above the polygon faces by means of a plane parallel block placed between the polygon base and the angle block. The calibration process consists in comparison of the angle block with one or more equivalent angular intervals of the polygon. Each angle is determined from the difference in the settings of an autocollimator when it is sighted on the two faces that define the angle. Two autocollimators, one for the polygon and the other for the angle block, are positioned 180 deg apart to minimize effects of asymmetrical thermal dimensional changes in the supporting surface plate.

A Precise Angular Standard

A 24-SIDED polygon of exceptional accuracy has been constructed by C. E. Haven and A. G. Strang of the National Bureau of Standards to serve as a basic standard of angular measurement. Made of precisely machined and polished gage blocks accurately positioned at measured angular intervals on a circular base plate, the NBS polygon permits the comparison of an "unknown" angle with consecutive angular intervals until the total of such intervals equal an integral number of perfect 360-deg angles. The polygon was designed primarily for use in the calibration of the 15-, 30-, and 45-deg angle blocks of the master sets that industry uses to control the shape—and hence the interchangeability and proper functioning—of mechanical parts produced by mass-production methods. However, the principle of the device is expected to find considerable application in the routine angular measurement work of the optical and mechanical industries.

Solid angular standards, or angle blocks, were developed during World War II as a result of the shortage of precise angular dividing equipment. They are hardened, ground, and lapped steel blocks about 3 in. long having specified angles between the two contact surfaces. Like gage blocks, they may be combined with little error by wringing to form the sum or difference of a pair; thus, a series of 16 blocks can be mounted with a solid square to give any single subdivision of a circle to the nearest ground.

Accuracy of the angle blocks used in this country is insured by NBS, which calibrates the master angle blocks with which manufacturers compare their working standards. In general, the angular values of a set of master angle blocks can be determined, using interferometric methods of comparison, without reference to an external standard, but the necessary accuracy is difficult to obtain for the larger angles. NBS therefore undertook to produce an angular standard that would permit direct calibration of 30- and 45-deg blocks. The 24-sided polygon that was constructed has 15-deg angles between adjacent faces and thus can be used to calibrate any multiple of this angle.

Calibration of an angle block by means of the polygon consists essentially in comparing the angle block with one or more angular intervals of the polygon. Angles are measured by sighting an autocollimator on the two faces that define an angle and then determining the angular difference between the two settings. Each polished face acts as a plane mirror and a sharp image of the autocollimator cross hairs formed. In practice, any error present in the calibration of the polygon is eliminated by comparing the angle block with a sufficient number of consecutive intervals to include an integral number of polygon rotations or circuits, that is to say, an integral number of perfect 360-deg angles. In this way it has been possible to determine the angles of master blocks with errors of approximately 0.1 sec.

The mechanical requirements for a standard polygon of the requisite accuracy for this type of work are quite rigorous. For example, the defining surfaces must be flat to 1 or 2 millionths of an inch over practically

their entire area, the surface roughness of the faces must average less than 0.5 microinch, and the variations in the angle between the defining faces and the axis of the polygon must not be greater than 15 sec. Construction of a solid polygon from a single piece of material to such limits constitutes a challenge to the best mechanical skill and equipment. It was therefore decided to assemble the polygon by fastening gage blocks, which were already available with satisfactory defining faces, to a circular base plate in such a way that their outer faces would form the standard polygon. To keep the diameter of the plate within reasonable limits, the gage blocks were placed in two layers of twelve each.

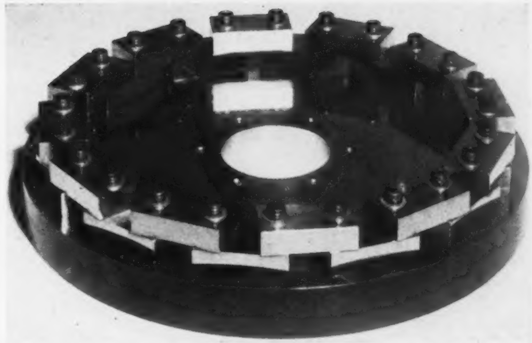
The circular base of the polygon is 0.75 in. thick and 8 in. in diameter. It was made of oil-hardened steel and heat-treated for maximum dimensional stability. After hardening, the base was ground on both sides and then hand-lapped until the error in parallelism of the two surfaces was less than 0.0001 in. and the maximum error in flatness of each surface was less than 0.00006 in. A rather high finish was imparted to one surface in the final lapping to permit wringing the special gage blocks in position.

Modified 0.750-in. rectangular gage blocks were used for the defining faces. All four lapped sides were plane to 0.000005 in. or better, and adjacent sides were square to 2 sec of arc. The surface roughness of each of the sides was less than 1 μin. rms. This was reduced still further by polishing with a cloth lap. The thickness (nominally 0.375 in.) of the 24 blocks in the group varied less than 0.00003 in. The bottom layer of blocks was so selected that adjacent blocks did not differ in thickness by more than 0.00001 in. This permitted at least partial wringing of the blocks in the upper layer to those in the lower layer and reduced distortion arising from the pressure of the clamping screws.

Twenty-four tapped holes in the base plate permitted the use of the same screws for fastening both the upper and lower layers of gage blocks. The holes were countersunk and then counterbored to a depth of $\frac{1}{4}$ in. to minimize distortion of the base caused by tension of the clamping screws.

The positioning of the gage blocks on the base plate was carried out on a carefully adjusted rotary table with the aid of 15-, 30-, and 45-deg angle blocks, a solid square, and an autocollimator. The 0-, 90-, 180-, and 270-deg faces were positioned by means of the square, and the intermediate faces by adding or subtracting 15, 30, and 45 deg from these positions.

Two autocollimators and a rotary table were used in calibrating the polygon. The polygon was mounted on the rotary table, and each autocollimator was placed on a substantial iron base with its optical axis line with the junction of the upper and lower layers of blocks. To prevent dimensional changes in the surface plate owing to the body heat of the observers, the entire apparatus, except for parts of the autocollimators, was enclosed in an insulated box. Each autocollimator was centered on the appropriate polygon



Twenty-four-sided polygon constructed by the Bureau to provide a precise basic standard of angular measurement. The defining faces of the polygon are provided by 24 highly polished gage blocks attached to an accurately machined and polished base plate in two layers of 12 each. Angles in multiples of 15 deg can be obtained from the polygon by the sighting of an autocollimator on the two faces which define the angle and then determination of the angular difference between the two settings.

face by viewing the image of the cross hairs with a low-power microscope. After recording the readings of the two autocollimators for one angular interval, the rotary table on which the polygon was mounted was then turned to present the faces of the adjacent angular interval. This process was repeated until every interval of the same nominal size had been measured and the circuit closed. In order to provide corrections of equal precision for all intervals, 552 measurements involving 76 closures were made to obtain all possible sums of consecutive angles. From these measurements corrections were derived statistically for each interval.

Although the NBS polygon was designed primarily as a master for angle blocks, similar assembled polygons should prove useful in a variety of fields. For example, simple polygons of a few blocks could easily be assembled for use as masters or gages in optical or machine work.

The NBS polygon is also well suited to the calibration of circular dividing equipment such as rotating tables. Alone it permit the calibration of 15-deg intervals; used in conjunction with other similar polygons it will measure intervals as small as 1 deg. The ease and precision with which defining faces can be positioned on an assembled polygon suggests the possibility of constructing a single polygon having, in addition to the usual larger intervals, one or more blocks set at such angles as to subdivide the principal intervals. The construction of such a polygon is now under way at NBS.

For further details, see Assembled polygon for the calibration of angle blocks, *by Clyde E. Haven and Arthur G. Strang, J. Research NBS* **50**, *45 (1953), reprinted as NBS Research Paper RP 2387, 10 cents from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.*

NEW ORDNANCE DEVELOPMENT

specialized equipment for study of effects of high acceleration on experimental ordnance components

RECENTLY completed shock and acceleration simulation devices, including a 91-foot drop tower, airguns, wind tunnel and centrifuges, are providing improved facilities for the ordnance development activities of the National Bureau of Standards. The new equipment is used primarily in studies of the effects of high accelerations—similar to those to which ordnance projectiles are actually subjected in normal use—on experimental ordnance components. Major equipment housed in the Bureau's Air Gun Building includes two air guns, one of them 96 ft long; a wind tunnel, used in related work, with a velocity of 300 ft/sec; and four centrifuges, one of which can produce acceleration of 60,000 g (g=acceleration of gravity) on 1-lb specimens. The Drop Tower, located near the Air Gun Building, is used for studies of the effects of various shock impacts on experimental objects; these impacts are obtained by dropping the objects onto various surfaces from various known heights.

The Bureau has long had a variety of major assignments in weapons development work for the Armed

Drop Tower and Air Gun Building (low white building behind tower) recently constructed at NBS. These new facilities are being used in connection with the NBS ordnance development program in studies of the effects of high accelerations on experimental ordnance components. Devices and components may be fired in projectiles from a 96-foot air gun, rotated in powerful centrifuges that produce accelerations up to 60,000 *g*, or dropped from the 91-foot Drop Tower onto steel or concrete anvils. Studies with the new facilities show whether experimental objects can stand the shock of being fired in a projectile.

FACILITIES AT NBS

Arm of the NBS Ultra-High-*g* Centrifuge H1. An 8-cylinder 16-horsepower automobile engine, working through a step-up gear box, drives the 37-inch-long centrifuge arm to a full speed of 11,000 rpm. Accelerations of up to 60,000 *g* can be produced in specimens mounted in the ends of the centrifuge arm.

Forces. It was at NBS that the first radio proximity fuze for nonrotating projectiles was developed during World War II and also, in cooperation with industry, the "BAT"—the first fully automatic guided missile to be successfully used in combat. The Bureau's ordnance development and guided missiles laboratories are currently engaged in a continuing program of research and development for the Department of Defense. Important in this work is the development of various electronic and electromechanical devices that will withstand being fired in ordnance projectiles.

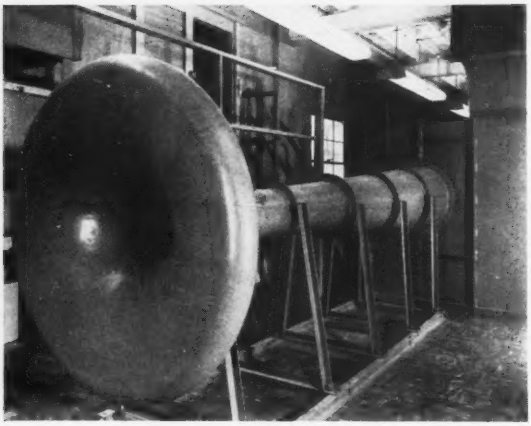
Air Gun, M2

The large NBS Air Gun (M2) is constructed from eight 90-mm gun barrels. The barrels are bored to 4-in. inside diameter, flanged, and bolted together to provide a straight length of 96 ft supported at intervals by concrete piers. A wall thickness of 1 in. provides sufficient strength for great latitude in working pressures.

Design of the NBS Air Gun is noteworthy in that the acceleration forces are not caused by sudden application of a very high air pressure to the projectile to give it a high initial acceleration. Instead, low-pressure air gradually brings the projectile (inside which are mounted the components to be tested) up to speed along the length of the long tube; then, to produce the desired accelerating force, the fast-moving projectile is rapidly stopped by letting it plow into a catcher box filled with sand, lead, or other material. By using projectiles of different materials and shapes, by adjusting the propelling force so as to produce different muzzle velocities, and by filling the catcher box with different materials, a wide range of negative accelerations can be applied to the components under study.

A 125-psi, 70-cu ft tank, fitted with a quick-release valve, supplies the propelling air. Impact velocities of projectiles are determined either photoelectrically or by measurement of the time interval between the breaking of two wires. Typical projectiles weigh from 6 to 18 lbs and attain velocities as high as 880 ft/sec. Weight and speed are thus comparable to those of an actual ordnance projectile fired from a weapon such as a trench mortar. The steel test projectile smashes into a stack of lead plates in the catcher box with such force that it penetrates some 8 in. into the lead.

Before construction of the large M2 air gun was begun, a prototype model M1 was built. The barrel of NBS Air Gun M1 consists of 22 ft of 1⅜ in. I. D.



Intake of the wind tunnel, another important ordnance development facility in the NBS Air Gun Building. Air velocities up to 300 feet per second are available.

tubing. Although the M1 was originally constructed only to test design feasibility, it has proved to be a useful piece of experimental equipment.

Ultra-High-*g* Centrifuge, H1

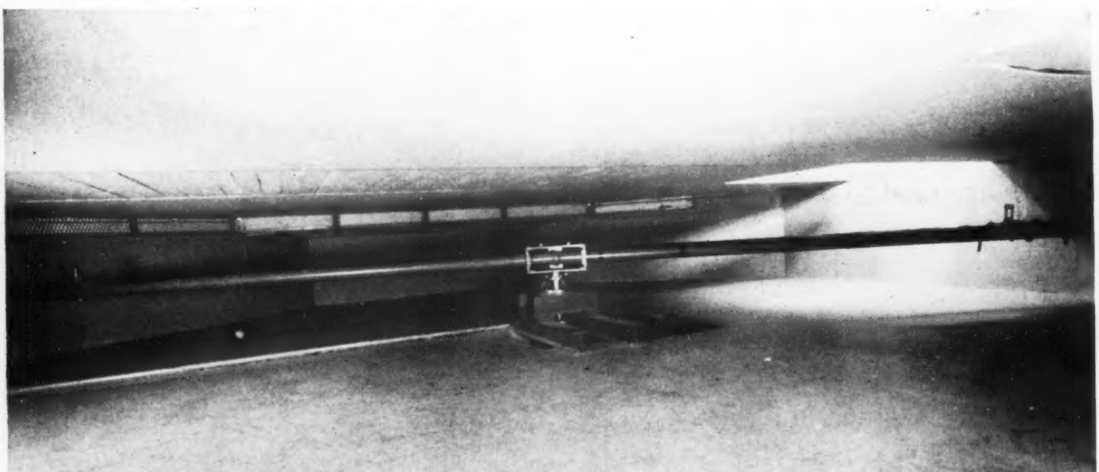
The NBS Ultra-High-*g* Centrifuge H1 was developed cooperatively by the Raymond Engineering Laboratory and the Bureau to apply an acceleration of 60,000 *g* to two specimens weighing as much as 1 lb each. The specimens rotate in a 37-in.-diameter circle with a full speed of 11,000 rpm; at this speed the specimens have a velocity of about 1,200 miles/hr, and the force at the hub section is more than 830,000 lb. The arm is machined from SAE 4340 steel heat-treated to an ultimate tensile strength of 176,000 lb/in^2, which was magnafluxed and X-rayed to insure freedom from cracks, voids, and other imperfections. The 2-in.-thick steel chamber in which the arm rotates is designed to be evacuated or filled with helium if desired. An 8-cylinder 160-horsepower automobile engine, working through a step-up gear box, supplies the large amount of power needed to drive the centrifuge to full speed. Electrical slip rings are provided to transmit information from the component under test to recording instruments.

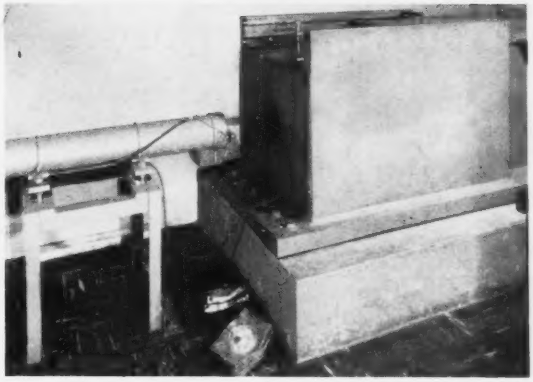
The tremendous speeds and forces involved in operation of the centrifuge call for a number of precautions. To minimize large unbalance forces caused by the very high rotational speeds the arm-shaft-bearing assembly is mounted on rubber O-rings. This allows the assembly to seek its own rotational center when acted on by an unbalanced load. Means must be provided for measurement of dynamic unbalance that may occur over the entire speed range. This is accomplished by means of two strain gages mounted on a beam over the drive shaft; the output from the gages is fed to control oscilloscopes which show when serious unbalance occurs. A reinforced concrete archway, 3 ft wide by 6 in. thick, provides protection in the plane of rotation of the centrifuge arms. Safety is augmented by the fact that the building at this point is about 8 ft below grade.

Heavy-Duty Low-*g* Centrifuge, L1

The NBS Heavy-Duty Low-*g* Centrifuge L1 was constructed to permit the testing of relatively heavy components—up to 150 lb including supporting fixtures—under the influence of relatively low acceleration forces, up to 100 *g*. The ends of the arms of this big centrifuge describe a circle 29 ft in diameter; the large

Heavy-duty low-*g* centrifuge, located in a safety pit under one wing of the NBS Air Gun Building. This big machine has an operating diameter of 29 feet and permits the testing of relatively heavy components—as much as 150 pounds—at relatively low accelerations, up to 100 *g*.





Left: **Loading the Air Gun with a test projectile. (Only about one-fourth of the length of the gun barrel is visible.) The object under study is mounted inside the hollow steel projectile. Low pressure air (125 psi) gradually increases the speed of the projectile throughout the long barrel.** ***Above:*** **Leaving the muzzle of the Air Gun at high speed, the projectile smashes into a catcher box containing sand, lead plates, or other material to provide the desired negative acceleration. Muzzle velocity is measured photoelectrically or by determination of the time between the breaking of two trip wires. Weighing about 18 pounds, the projectile arrives with such power that it penetrates 8 inches into a stack of lead plates.**

diameter was selected to minimize the variation in *g* throughout specimens under test. Power to drive the unit at speeds up to 165 rpm is provided by a 20-horsepower motor-generator set. Located for safety in a pit in a wing of the Air Gun Building, the centrifuge is surrounded by a concrete wall for additional protection.

In addition to these two special centrifuges, H1 and L1, the building is equipped with a 1,000 *g* and a 10,000 *g* centrifuge for work of a more routine nature.

Drop Tower

The NBS Drop Tower provides a convenient means for elevating test objects to heights up to 87 ft 8 in. and dropping them onto various anvils, steel, concrete, wood, or sand. The installation is based on the 91-ft Beacon Tower designed by the Civil Aeronautics Administration. In the bottom of the tower is a small house, about 14 ft square and 10 ft high, for personnel and equipment. A central vertical shaft, 2 ft square, extends the full height of the tower through a trapdoor in the roof of the house. The object under study is mounted in a "dropping block" which is fastened to the carriage of a chain-drive elevator by means of an electrical bomb-release mechanism. When the elevator has carried the object to the desired height, the operator presses a button to release the dropping block. Accelerometers may be fastened to the dropping block to measure the impact acceleration, and provision is made for several other types of instrumentation. Maximum impact velocity is 74.5 ft/sec, or about 50 miles/hr. Accelerations as high as 50,000 *g* are obtained on impact.

Standard Petroleum Measurement Tables

NBS Circular 410, *National Standard Petroleum Oil Tables*, and its *Supplement* will be withdrawn from circulation January 1, 1954. The information given in Circular 410 has now been incorporated in the *ASTM–IP Petroleum Measurement Tables* recently issued by the American Society for Testing Materials and the Institute of Petroleum (Great Britain). The new tables are available from the American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pennsylvania, at a cost of $8.75 ($6.50 to ASTM members). Tables 5 and 7 of the ASTM–IP tables may also be purchased from the ASTM in separate reprint form for $1.00 and 50 cents, respectively, with a reduction on quantity purchases. Table 5 covers the reduction of observed API gravity to API gravity at 60° F. Table 7, which replaces the *Supplement to NBS Circular 410*, covers reduction of volume to 60° F against API gravity at 60° F. Other individual tables are being reprinted.

The withdrawal of Circular 410 was originally scheduled for July 1, 1953, but was postponed in order to allow time for the republication of the tariffs of pipe line companies and the necessary changes in other legal and regulatory documents which make special reference to Circular C410.

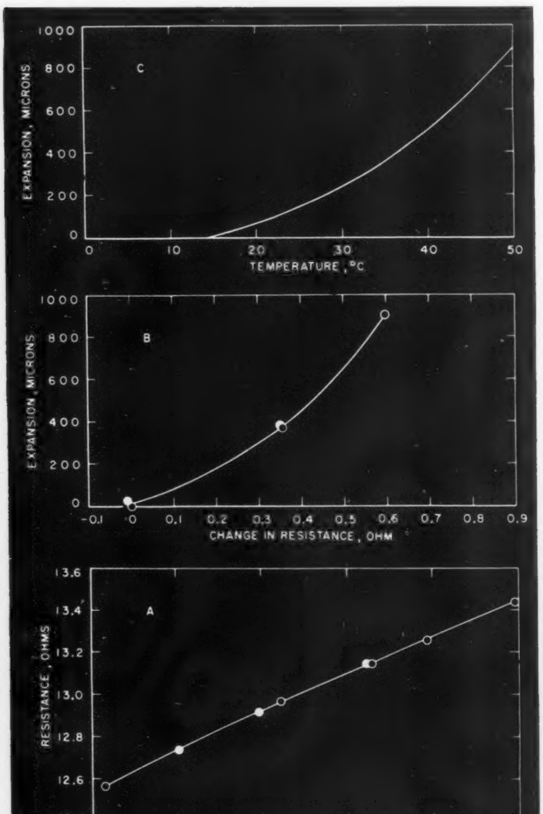
Thermal Expansion of Invar Surveying Tapes

A NEW method for determining the coefficients of linear thermal expansion of invar [1] geodetic surveying tapes has been developed by Peter Hidnert and R. K. Kirby of the Bureau. Based on a determined relationship between the electrical resistance and the temperature for each invar tape, the NBS technique consists principally of measurements of expansion and electrical resistance of the tape when heated by passing a direct current through it without changing the temperature of the laboratory. The new method is not only more precise but also much more rapid and convenient than the previous method, which required measurements at different ambient temperatures.

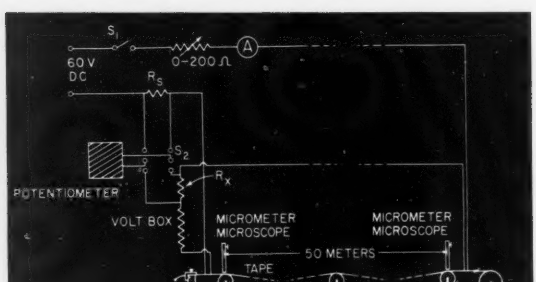
For accurate determinations of long distances with geodetic tapes, as in measurements of base lines by the U. S. Coast and Geodetic Survey, the coefficient of thermal expansion of each tape is needed in order to calculate the lengths at various atmospheric temperatures. Over the past half century NBS has determined the coefficients of expansion of many invar tapes for Government agencies. The measurements are carried out in a specially designed underground laboratory. Until now the length of each tape was measured at several different constant temperatures from 5° to 35° C by comparison with a distance laid off with a 5-meter steel standard maintained at 0° C by packing it in melting ice. To obtain the various constant temperatures it was necessary to change the temperature of the entire laboratory. Several days were allowed for the equipment to reach equilibrium conditions at each temperature. Furthermore, additional time and effort were spent in making the large number of precise measurements of length and temperature that were required.

In the new NBS method the temperature of the laboratory is held constant at a convenient temperature. The tape, under a specified tension, is supported in the same manner as used in the field, but it is electrically insulated from the supporting apparatus. Micrometer microscopes are focused on the terminal graduations of the tape, and the change in length or linear expansion is observed directly when the tape is heated by passing a direct current through it. The electrical resistance corresponding to each observation for linear expansion is determined by a potentiometer method. Measurements of the lengths of the tape by means of the 5-meter steel standard are no longer needed for expansion determinations. The temperature coefficient

[1] Invar is a nickel steel containing about 36 percent nickel. Its coefficient of linear expansion is very small at ordinary temperatures.



Left: **Observed and derived data obtained on a 50-meter invar geodetic tape. A: observed electrical resistance (ohms per 51.2 meters) versus temperature. B: observed linear expansion (microns per 50 meters) versus change in electrical resistance (ohm per 50.4 meters) from the value of the resistance of 15° C. C.: derived relation between linear expansion (microns per 50 meters) and temperature, obtained from the observed data in A and B. *Below:* Schematic diagram of a potentiometer method used in determination of the electrical resistance of geodetic surveying tapes. R_x is the resistance of the section of the volt box connected across the potentiometer, and R_s is the resistance of the four-terminal current shunt.**



Left: Measurement of electrical resistance of surveying tape in the tape testing laboratory by a potentiometer method. **Right:** Observation being made at a terminal graduation of a geodetic surveying tape in the tape testing laboratory. In the new NBS method for determination of coefficients of thermal expansion of invar tapes, each tape is heated by a direct current passed through it while the ambient temperature of the laboratory is held constant. The resultant change in length or linear expansion is observed directly by means of two microscopes focused on the terminal graduations of the tape.

of resistance of the tape is used to convert the observed changes in resistance to temperature changes. Then, from the length of the tape, the observed changes in length, and the corresponding temperature changes, the coefficient of linear thermal expansion is calculated. The temperatures at which the observations apply are obtained by adding the determined temperature changes to the initial temperature of the tape as determined by thermometers hung in close proximity to the tape.

The temperature coefficient of resistance of each tape can either be obtained experimentally or computed from an empirical relationship derived at NBS between the temperature coefficient of resistance and the mass resistivity of invar tapes. The mass resistivity is easily determined by multiplying the resistance per unit length by the mass per unit length.

Coefficients of expansion of five 50-meter invar tapes obtained by the new method have been found to be in good agreement with those obtained for the same tapes by the old method. The probable errors of the coefficients of expansion determined by the new method are approximately 0.01×10^{-6} per degree C and are less than the probable errors of the coefficients of the same tapes by the former method.

For further technical details, see A new method for determining linear thermal expansion of invar geodetic surveying tapes, *by Peter Hidnert and Richard K. Kirby, J. Research NBS* **50**, *179 (Apr. 1953) RP2407.*

Symposium on Barium Titanate Accelerometers

MORE than 250 scientists and engineers attended a Symposium on Barium Titanate Accelerometers held in Washington, D. C., on May 14 and 15 under the sponsorship of the Office of Basic Instrumentation of the National Bureau of Standards. Sixty-seven industrial and university laboratories were represented, as well as 44 U. S. Government agencies and four foreign government agencies. Twenty-seven invited papers were presented by representatives of Bell Telephone Laboratories, Brush Laboratories Company, Gulton Manufacturing Company, Boston Insulated Wire and Cable Company, Keithley Instruments, the Naval Research Laboratory, the Naval Ordnance Laboratory, the David Taylor Model Basin, and NBS. A number of discussion periods were also included. The program was arranged by Dr. T. A. Perls of the NBS staff.

In recent years developments in the field of ceramics have made available piezoelectric materials that are both sensitive and easily fabricated. One of these, barium titanate, has been used to make small piezoelectric accelerometers that are in many ways superior to other instruments now employed to measure vibration and shock. Two accelerometers of this kind were developed by NBS in 1951 and 1953 in connection with a program of basic instrumentation sponsored at the Bureau by the Departments of the Navy and the Air Force and the Atomic Energy Commission. The advantages of barium titanate accelerometers for measurement of high-frequency vibrations and the relatively low cost at which they can be constructed have caused a large number of different organizations to undertake the development of such instruments for particular applications. However, the data obtained in different laboratories have sometimes been at variance; and many workers have not been cognizant of the results obtained by others working in the field. The Symposium was held to provide a means by which the various groups engaged in research and development on barium titanate accelerometers could come together for informal discussion of problems of mutual interest, learn more

about available data and proposed theories, and resolve or point out inconsistencies between the results obtained by different investigators.

The Symposium included four half-day sessions. The first of these dealt with the properties of barium titanate and titanate mixtures. A discussion of methods of polarization brought out the need for further investigation concerning the most effective polarizing techniques for the various materials available. A possible dependence of the charge sensitivity on crystal size was another topic that appeared to require further exploration. This session also included discussions of stability of barium titanate ceramics; generated voltage as a function of applied compressive force; and the effects of temperature and composition on elastic, piezoelectric, and dielectric constants.

Two half-day sessions were given over to discussion of design factors and performance tests of barium titanate accelerometers. Problems of construction, calibration, frequency response, tests of linearity at high accelerations, temperature and pressure effects, and cable noise were considered. New information was given on the transverse response of barium titanate accelerometers and on methods of obtaining calibrations at frequencies up to 10,000 cycles per second and at accelerations up to 9,000 *g*. The present status of low-noise cables for use with small crystal-type accelerometers was presented from the point of view of the manufacturer. An open discussion on pressure effects brought out the desirability of giving quantitative data regarding the output to be expected from transient pressures.

The final session dealt with instrumentation associated with the accelerometers. Some of the limitations of commercially available as well as laboratory-designed cathode followers were discussed, together with various methods for remedying these difficulties. Other topics included the effect of capacitance in the cathode-follower output circuit, transformer coupling to long cables, and the characteristics of integrators and differentiators used to obtain accelerometer outputs proportional to velocity and jerk (time rate of change of acceleration).

Thirty-Eighth National Conference on Weights and Measures

ATTENDANCE at the Thirty-Eighth National Conference of Weights and Measures, May 19–22, 1953, exceeded that of all previous meetings of the Conference, both in total number of delegates and number of states represented. This increased participation by the states evidences a growing interest in the importance of uniform weights and measures laws and administration. The 430 delegates represented many cities and counties, the Federal Government, manufacturers, railroads, business, industry, and trade associations, in addition to the 39 states and the District of Columbia.

The Conference, sponsored by the National Bureau of Standards, met in Washington, D. C. The function of the Bureau in the field of weights and measures administration is advisory only and stems from the responsibility for (1) the custody, maintenance, and development of the national standards of measurement and the provision of means and methods for making measurements consistent with those standards; and (2) cooperation with the states in securing uniformity in weights and measures laws and methods of inspection. The Federal Government has no regulatory authority in this field, which is entirely the responsibility of state and local governments.

Actions by the Conference are recommended to the states for official promulgation. The Thirty-Eighth National Conference adopted a Model Regulation on Package Marking Requirements, which is patterned after the Federal Food, Drug, and Cosmetic Act, as well as recommended methods of sale of anhydrous ammonia and other liquid chemical fertilizers with pressure characteristics; pre-heated fuel oils; peat moss in package form; rope; seeds (agricultural, horticultural, and floricultural); and pickles and pickle products in package form.

A tentative code for farm milk tanks offered by the Conference Committee on Specifications and Tolerances was adopted, as were minor amendments to the scale code.

These codes and amendments are incorporated into National Bureau of Standards Handbook 44, *Specifications, Tolerances, and Regulations for Commercial Weighing and Measuring Devices*, and are recommended by NBS for official adoption by the states. During the Conference it was announced that 26 states had officially adopted the Handbook 44 codes and that many other states are applying the provisions of the codes in their enforcement procedures.

During the 4-hour meeting of the Conference, which was organized in 1905, formal presentations were given on such topics as prepackaged foods, flour weights, automatic packaging machinery, livestock weighing supervision, electronic scales, technicalities in weights and measures court cases, the proposed international conference on legal metrology, and the performance of inspectors and gasoline pumps. Open forums, introduced by formal presentations, were held on ice-cream measure-containers, paper milk containers, highway truck weighing, and remote gasoline pumps.

The delegates watched demonstrations of two flow meters, an electronic meter developed by H. P. Kalmus of the NBS staff and a mechanical meter developed by a commercial firm. Instructions in the operation of both were heard.

The Conference Committee on Weights and Measures

Education reported the compilation of answers to a questionnaire sent to weights and measures officials. These answers indicated that the officials are desirous of further and rather extensive educational services from the Bureau.

Dr. Astin was reelected President of the Conference. Six vice presidents were elected: G. F. Austin, Jr. (Detroit, Mich.); J. E. Boyle (Maine); F. M. Greene (Connecticut); J. R. Jones (South Carolina); J. W. Reese (Iowa); and A. C. Samenfink (Rochester, N. Y.). W. S. Bussey (NBS Office of Weights and Measures) was reelected Secretary, and J. P. McBride (Massachusetts) was elected Treasurer. The Thirty-Ninth National Conference on Weights and Measures was scheduled by the Executive Committee to meet May 17–21, 1954.

Publications of the National Bureau of Standards

Periodicals

Journal of Research of the National Bureau of Standards, volume **51**, number 1, July 1953 (RP2426 to RP2431 incl.). Annual subscription $5.50.

Technical News Bulletin, volume **37**, number 7, July 1953. 10 cents. Annual Subscription $1.00.

CRPL–D107. Basic Radio Propagation Predictions for October 1953. Three months in advance. Issued July 1953. 10 cents. Annual subscription, $1.00.

Research Papers

Reprints from Journal of Research, volume **51**, *number 1, July 1953. Single copies of Research Papers are not available for sale. The Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., will reprint 100 or more copies, and request for the purchase price should be mailed promptly to that office.*

RP2426. Fabrication of radio-frequency micropotentiometer resistance elements. Lewis F. Behrent.

RP2427. Properties of some masonry cements. D. N. Evans, A. Litvin, A. C. Figlia, and R. L. Blaine.

RP2428. Subsieve particle size measurement of metal powders by air elutriation. Rolla E. Pollard.

RP2429. Eigenvectors of matric polynomials. Murray Mannos.

RP2430. The system barium oxide-boric oxide-silica. Ernest M. Levin and George M. Ugrinic.

RP2431. Errors introduced by finite space and time increments in dynamic response computation. Samuel Levy and Wilhelmina D. Kroll.

Circulars

C533. Method for determining the resolving power of photographic lenses. F. E. Washer and I. C. Gardner. $1.00.

C533 Supplement. Charts. 75 cents.

C539 Volume **1**. Standard x-ray diffraction powder patterns. H. E. Swanson and Eleanor Tatge. 45 cents.

C539 Volume **2**. Standard x-ray diffraction powder patterns. H. E. Swanson and Ruth K. Fuyat. 45 cents.

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TECHNICAL NEWS BULLETIN

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SINCLAIR WEEKS, *Secretary*
NATIONAL BUREAU OF STANDARDS
A. V. ASTIN, *Director*

August 1953 **Issued Monthly** **Vol. 37, No. 8**

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